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INNOVATIVE ROADWAY DESIGN FOR RECREATION AREAS. (U)

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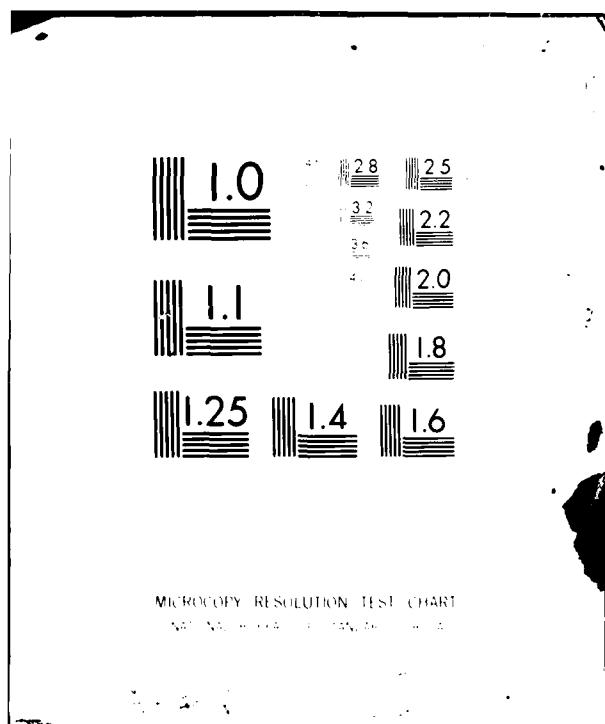
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INNOVATIVE ROADWAY DESIGN FOR RECREATION AREAS

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By James W. Epps, Marion W. Corey

Mississippi State University

Mississippi State, Miss. 39762

and

M. John Cullinane

Environmental Laboratory

U. S. Army Engineer Waterways Experiment Station

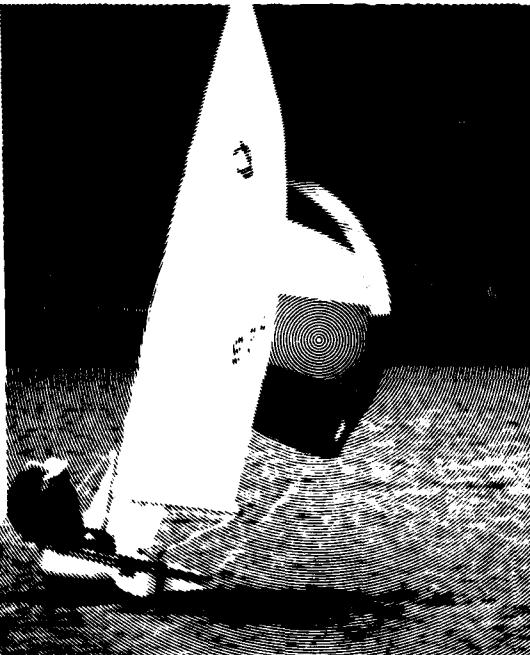
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20. ABSTRACT (Continued).

has depended heavily on traditional highway design practice with a resultant cost penalty. Standard design criteria and construction techniques are being increasingly viewed by present day planners as overly conservative and not widely applicable to implementation of cost-effective low volume road systems.

In recognition of the need for the application of the latest roadway planning and design techniques, a review of available literature on the topic was accomplished. The objective of this effort was to develop information that will assist Corps of Engineers Districts in optimizing the design and operation of recreation area roadway systems.

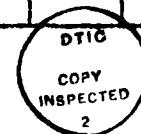
Efforts have been directed at four categories of roadway planning and design activities where cost savings may be anticipated: These activities include: (1) development of new planning and design techniques; (2) revision of geometric design criteria, (3) investigation of new pavement materials and design techniques, and (4) development of rapid and effective maintenance methods.

Interim results of the study indicate that techniques are available that have the potential for considerably reducing the cost of recreation area roadway construction. Automated planning techniques are particularly relevant.

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Preface

This report presents the results of a survey to determine the existence of innovative and/or alternative roadway planning, design, and construction techniques applicable to the development of transportation facilities for Corps of Engineers (CE) recreation areas.

The study was conducted under contract between the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., and Mississippi State University (MSU), Mississippi State, Miss., under Contract Nos. DACW39-80-C-0007 and DACW39-80-C-0008 (Work Unit 31694 "Planning and Design Criteria for Recreation Roads and Sanitary Facilities").

This report was written by Drs. James W. Epps and Marion W. Corey, MSU, and Mr. M. John Cullinane, Environmental Engineering Division (EED), Environmental Laboratory (EL), WES. Mr. Michael R. Waring, Environmental Resources Division (ERD), was the Principal Investigator for the work unit. Dr. Adolph Anderson, EL, was Program Manager for the Recreation Research Program. The study was under the supervision of Dr. Conrad J. Kirby, Chief, ERD, and Dr. John Harrison, Chief, EL.

Commanders and Directors of WES during the time of this study and preparation of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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Conversion Factors, U. S. Customary To Metric (SI)
Units Of Measurement

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
feet per foot	0.3048	metres per metre
feet per minute	0.3048	metres per minute
inches	25.4	millimetres
kips (force)	4.448222	kilonewtons
miles per hour (U. S. statute)	1.609347	kilometres per hour
miles (U. S. statute)	1.609347	kilometres
pounds (force)	4.448222	newtons
tons (mass) per hour	907.1847	kilograms per hour
tons (2000 lb, mass)	907.1847	kilograms

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9) (F - 32)$. To obtain Kelvin (K) readings, use $K = (5/9) (F - 32) + 273.15$.

INNOVATIVE ROADWAY DESIGN FOR
RECREATION AREAS

1. Background.

a. It is estimated that the construction of access and circulation roads contributes approximately 60 percent of the costs associated with development of Corps of Engineers (CE) recreation areas (McNamara, Moore, and Baerwald 1975). Using this as a premise, it is easily hypothesized that the development or adaptation of innovative/alternative roadway planning, design, and construction practices could result in a potentially large dollar savings for the CE recreation program. This paper is designed to present the results of a study to identify innovative/alternative techniques being utilized by Federal, State, local, and private sector organizations which have potential application for the planning, design, or construction of roadways in CE recreation areas. Although design criteria are an important aspect of the overall recreation roadway implementation process, it is not the objective of this paper to formulate and provide comprehensive planning or engineering guidance for the construction of recreation area roadways.

b. The planning and construction of CE recreation area roadways are primarily controlled by Engineering Regulation (ER) 1110-2-400 as set forth in Engineer Manual (EM) 1110-2-400 (Department of the Army, 1972) which relates to the design of roads at reservoir projects. EM 1110-2-400 is currently under revision and a draft Engineer Manual, "Recreation Area Design - Access and Circulation," has been circulated for field review and comment under Engineer Circular (EC) 1110-2-209 (Department of the Army, 1979). In addition, each District or Division may rely on a variety of other published and unpublished information including criteria developed by the following agencies: Corps of Engineers, Federal Highway Administration (FHWA), American Association of State Highway and Transportation Officials (AASHTO), other Federal

agency publications (Forest Service and National Park Service), and in-house experience.

c. ER 1110-2-400 and EM 1110-2-400 provide the CE planner and engineer with general guidance for the planning and design of recreation roadway systems. Field personnel must rely on the myriad of other publications for the detailed guidance necessary to implement required roadway systems. The lack of a uniform national criteria for CE recreation area roadways has resulted in somewhat contradictory perceptions. Some argue that recreational roads found at CE projects are not adequately designed to meet current and expected recreation needs, and others argue that the CE wastes taxpayer's money by overdesigning its roads by using unnecessarily high standards.

d. The Construction Engineering Research Laboratory (CERL) conducted a study in 1975 which attempted to: (1) identify and quantify existing (1975) recreation road design practices of the CE, States, and other Federal agencies; and (2) develop a set of geometric and aesthetic design standards for implementation on a CE-wide basis. To date, the CERL study (McNamara, Moore, and Baerwald, 1975) is perhaps the single most comprehensive treatise on recreation roadway design. The report provides the planner or engineer with a single source compendium of geometric design standards for recreation areas. Design guidelines developed by the CERL study are based on a survey and subsequent evaluation of: (1) planning and design practice within the CE, (2) planning and design guidance used by other Federal and State agencies, and (3) publications of AASHTO. The criteria developed in the CERL study present a rational approach to the development of recreation roadway geometric design criteria. The criteria presented are based on conventional design concepts with added recognition of the unique nature of recreation area roadways, specifically the reduced design speeds found in recreation areas. The CERL report concentrates on the development of geometric design criteria with little discussion of the other aspects of roadway design.

e. Although geometric design criteria are an important component of roadway planning and design, geometric design is only one aspect of the process that must be considered. The planning and design of recreational area roads may be viewed as a three-phase process involving: (1) routing of the traffic flow based on destinational analysis, (2) geometric design of the roadway system, and (3) design of appropriate pavement structures. Conduct of this three-phase process requires the collection and analysis of significant amounts of information, both quantitative and qualitative. Specifically, the planner or designer must determine: (1) the destination to which access must be provided; (2) the functional classification and segmenting of proposed roadways; (3) the types of vehicles to be accommodated, including physical dimensions and operating characteristics; (4) the volume of traffic to be accommodated by each functional road category; and (5) the appropriate design speeds for each functional road category. Once these data are collected and analyzed, the planner or designer can proceed with implementation of an efficient transportation system for the specific recreation area.

f. Design criteria for recreational roads are generally based on conventional practices associated with the design of highways. In many cases, there is little, if any, recognition of the unique requirements placed on recreation roadways. Innovative design concepts and criteria are required for the cost-effective implementation of recreational roadway systems.

2. Innovative Concepts.

a. The planning and design of roadways for recreation areas in the United States has followed traditional engineering practice. Design standards have been extrapolated from criteria developed for high level roadways which in many cases do not recognize the nature of the low volume roads generally found in recreation areas. Indeed, it is probable that those cases discussed by field personnel as examples of gross

overdesign have resulted from a misapplication of valid high volume road design criteria to low volume road design.

b. Planning and design of recreation area roadways have been strongly influenced by the Federal Government through the FHWA, private organizations through the AASHTO, and the 50 State highway departments. All 50 States have adopted specific design criteria for planning and design of roadways. Most of these State design standards emphasize the construction and materials aspects of roadway design rather than geometric design.

c. Standard requirements and techniques are being increasingly viewed by present-day planners and designers as overly conservative and not widely applicable to implementation of low volume road systems. The increasing costs of labor and materials have been the primary driving force for development of innovative/alternative (I/A) techniques for providing cost-effective low volume roadway systems. The underlying goal of each I/A system has been the provision of acceptable roadway systems which meet user requirements and expectations while minimizing system life cycle costs. Research and development efforts have been primarily directed at four categories of roadway planning and design activities where cost savings may be anticipated. These activities have included: (1) development of new planning and design techniques, (2) revision of geometric design criteria, (3) investigation of new pavement materials and design techniques, and (4) development of rapid and effective maintenance methods.

3. Planning and Design Techniques.

a. Increased costs and environmental concerns require roadway planners and engineers to investigate and more thoroughly evaluate the consequences of road location decisions. As the manager of a road

system totaling over 200,000 miles,* the Forest Service has investigated numerous I/A planning and design techniques which have possible application to the CE recreation area scenario. Three techniques, primarily using a combination of computers and revised field design techniques, are worthy of discussion.

b. A technique using topometrics (Burke, 1975) has been developed to assist the planner or engineer in efficient evaluation of alternative routes. Topometrics is the process whereby numeric information is obtained from topographic maps by measuring three-dimensional differences of coordinates. The topometric process translates graphic position into a format that lends itself to numeric methods of analysis. The Forest Service system used desktop computers with digitizers, plotters, printers, and specially designed software routines to offer a low cost, readily available route evaluation system. The system allows the user to evaluate routes based on horizontal alignment, earthwork, and mass diagram computations. The technique has the user participate in an interactive process that allows him to see the results of basic decisions, make desired changes, and carry out many more design cycles than are possible with manual methods. Alternative route evaluation can be conducted at a rapid rate, up to 1,000 feet per minute, depending on map scale. The system provides a quantitative output enabling the user to easily evaluate cost, safety, and aesthetic factors.

c. In addition to evaluating such factors as cost and safety, the planner or engineer may address other more subtle considerations. Route aesthetics are a function of the total amounts of material moved, depths of cut and fill, exposure of cut and fill slopes, road suitability, and proximity to sensitive areas such as recreation sites, viewing points, and scenic overlooks. The Forest Service concept allows consideration of these factors during the planning stages of route evaluation rather

* A table of factors for converting U. S. customary units of measurement to metric (SI) is presented on page 3.

than at the design stage. Unacceptable routes can be identified and eliminated and the most economic and environmentally promising routes can be scheduled for field verification.

d. The Forest Service (George, 1975) also utilizes a computer-aided design system called the Forest Service Road Design System (FSRDS). The FSRDS is a comprehensive set of interrelated computer programs for processing road designs from the initial traverse to construction earthwork quantities. Though somewhat complex and developed primarily for design of lengthy low-class road systems, portions of the FSRDS have possible applicability to design of CE recreation area roads. The FSRDS is a "computer-aided" system in which the user is relieved of the repetitive computational tasks associated with roadway design. The user is allowed the luxury of considering more imaginative concepts and thus generating better designs. The complete FSRDS system contains over 30 interrelated design programs and provides the user with data on which to make a decision as to his next course of action.

e. Although FSRDS will handle the design of any individual type of road, it was primarily developed for the evaluation of low volume roads. There are several individual programs within the system that allow efficient design of low volume roads. The design modules require minimum inputs of profile grade, slope selection information, template information, and earthwork compaction factors. The computed output for each roadway station includes: (1) grade elevations; (2) average side slope; (3) topography limits--the distance left and right of baseline centerline that the design template can be moved; (4) limits of cut and fill--how far the template can be shifted left and right of baseline centerline based on maximum cut and fill height; (5) daylight offset; (6) self-balanced offset; and (7) approximate station-by-station quantities.

f. The Forest Service has used FSRDS for more than 15 years and has great confidence in the system's efficiency and effectiveness as a

tool for helping the roadway designer and the on-the-ground land manager make decisions concerning road design and construction. The Forest Service has found that the system allows the user to fit the road to the ground with minimum impact and still consider cost, safety, and aesthetic factors.

g. The previously discussed concepts developed by the Forest Service have stressed the use of computers to enhance and accelerate the planning and design process. The Forest Service has also investigated techniques involving field design of forest roads (Bowman, McCrea, and Fonnesback, 1975). Although the technique is primarily suitable for the design of low standard roads, the concepts may have application to CE recreation road planning, design, and construction, particularly local, sublocal, and service roadways.

h. Prior to development of the field design methodology, the Forest Service used the conventional P-line, L-line survey-design methodology. This conventional method of roadway design involves the establishment of roadway slope stakes through the use of a preliminary survey of the road line (called a P-line survey), an office design from the P-line data, and an additional survey of the designed road line (called a location or L-line survey) to establish a line from which to stake the roadway slope. The road is then slope staked and referenced prior to construction. The field design methodology essentially eliminates the initial P-line survey, or actually consolidates the P-line survey office design and L-line into one continuous process.

i. Development of the field design methodology has been evolutionary rather than revolutionary. For the design of low-class roads, the Forest Service reports substantial savings in manpower and design efforts. In one case, survey and design of a 3.5-mile low type road was accomplished in 12 days. Conventional P-line methods were estimated to require 3 months. The field design methodology is generally

estimated to require only 10 to 15 percent of the effort required for conventional design.

j. The field design methodology has not only resulted in manpower savings, but has produced aesthetically pleasing roadways with minimal impact on the land. Greater environmental impact has been found when conventional office design techniques are utilized. In test cases, field-designed roads were found to be indistinguishable from those that are conventionally designed.

k. In summary, the Forest Service has developed three cost-saving techniques having potential applicability to the planning and design of CE recreation area roadways. These techniques appear to be suitable for further investigation and implementation, in modified form, on a trial basis by the CE.

4. Geometric Design Concepts.

a. The second roadway planning and design activity where possible cost savings can be generated is that of geometric design. Geometric design is the design of the visible dimensions of a highway to form or shape the facility to the characteristics and behavior of drivers, vehicles, and traffic volume (McNamara, Moore, and Baerwald, 1975). In the design of recreational roadways, geometric design standards have a significant impact on the cost of the roadway system. Geometric overdesign may create as much or more economic waste as pavement overdesign.

b. As previously discussed, the 1975 CERL study developed a comprehensive set of geometric design standards for recreation area roadways. However, the importance of using appropriate geometric design criteria is such that added discussion of some basic design concepts is in order. The geometric design criteria reexamined during the study described herein include: (1) design speed, (2) horizontal alignment, (3) vertical alignment, and (4) cross section elements.

c. The design speed of a roadway is defined as "the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design features of the highway govern" (AASHTO, 1965). Design speed should be selected with respect to the character of the terrain and the level of roadway which is to be constructed. Current design standards are generally based on design speeds ranging between 30 and 80 miles per hour. For recreational roadway systems, however, 20- to 30-miles-per-hour designs should be considered far more suitable and economic. The use of a reduced design speed may provide for the reasonable reduction of other design parameters related to the design process, e.g. sight distances and reaction times. McLean (1979) suggests that for design speeds in the 20- to 30-miles-per-hour range, driver reaction time can be reduced from 2.50 to 1.50 seconds in areas where the driver will not become relaxed over a long period of time. This would apply to those areas where the driver's attention is not being distracted by the surroundings such as in the terminal areas or in areas where vehicle and/or pedestrian activity is high. Isolated areas where the driving act becomes monotonous are not appropriate segments for reduction of design reaction times. Design speeds are the controlling factor in developing horizontal and vertical alignment.

d. The design and control of horizontal alignment in a recreational area using conventional design concepts has tended to restrict the economical design of the roadway. Conventional design provides for a fixed-circular vehicle trajectory to avoid a severe driver reaction to the curvature. In addition, sight distance through the curve has always forced longer radii to improve driver visibility at design operating speeds. Coefficients of side friction f_s in the range of 0.11 to 0.16 have been selected with little regard to design speed except in the 30- to 80-miles-per-hour range. In the lower design speed ranges, higher values of f_s may be used because: (1) vehicles do not follow a fixed-circular path, and (2) drivers tend to cut the corner of the curves to lessen the severity of curvature (McLean, 1979). Table 1 presents a

comparison of conventional and reduced design values.

Table 1
Comparison of Conventional and Reduced Design Criteria

Design Speed (mph)	Conventional Design f_s	Reduced Design f_s	Minimum Radius*	Maximum Degree of Curve**
30	0.16	--	231	24.8
25	0.16	--	160	35.8
20	0.16	--	103	55.6
30		0.16	231	24.8
25		0.17	154	37.2
20		0.18	95	60.3

* Minimum radius can be calculated for conventional maximum super-elevation rate ($E_{max} = 0.10$ ft/ft) by the relationship (AASHTO, 1965):

$$R_{min} = \frac{V}{15(E_{max} + f_s)}$$

where V = velocity, mph

** Maximum degree of curve can be calculated by the relationship (AASHTO, 1965):

$$Dc_{max} = \frac{5729.6}{R_{min}}$$

e. Correlations between design speed and actual speed through horizontal curves have shown that, in the lower speed ranges, conventional design may be sacrificed for economics and still provide a safe alignment (Craus and Livneh, 1978). Figure 1 and Table 2 provide a description of these effects.

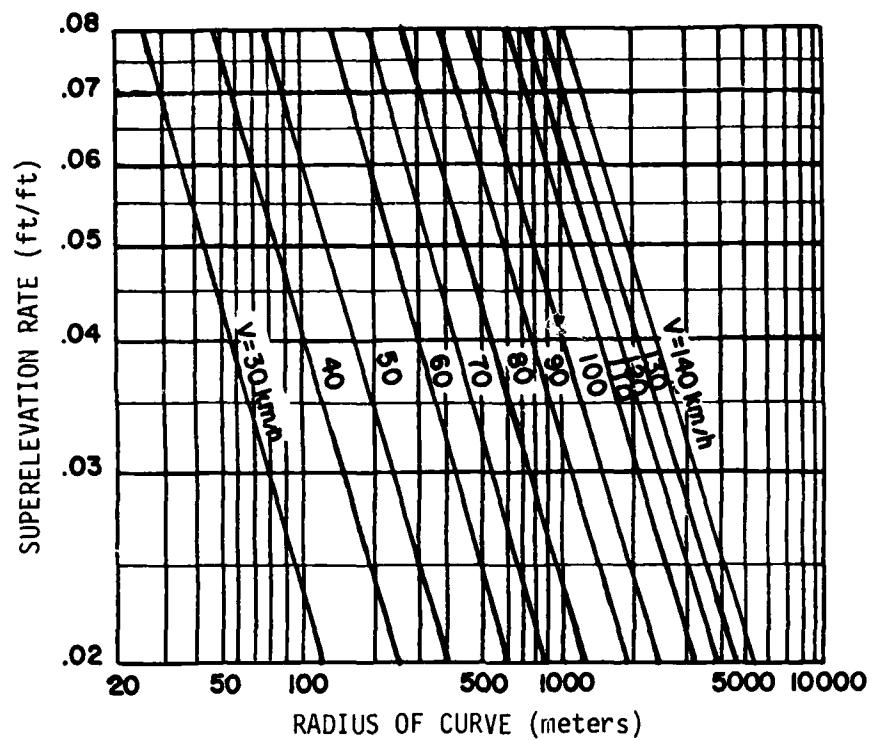


Figure 1. Relation between curve radius and superelevation rate, including minimum radii (Craus and Livneh, 1978).

Table 2
Distribution of Speeds as a Function of Design Speed
(Craus and Livneh, 1978)

Design Speed (mph)	Curve Radius (feet)	Low Critical Speed (mph)	Comfort Speed (mph)	High Critical Speed (mph)
18.6	82.0	8.57	9.82	21.06
24.9	154.2	11.74	13.36	27.96
31.1	255.9	15.16	17.58	34.79
37.3	400.3	18.95	21.87	41.94

f. Maintenance of adequate sight distance is a significant consideration in the selection of the degree of curve to be used in horizontal

alignment. Recommended sight distances are approximately 150 and 200 feet for design speeds of 20 and 30 miles per hour, respectively (Kearney, 1979). These values have been developed for conventional reaction times (2.5 seconds) and coefficients of friction (0.35). If the road segment is suitable, design reaction times may be reduced to 1.5 seconds and the coefficients of friction may be increased slightly. Table 3 presents a comparison of conventional and reduced design values.

Table 3
Comparison of Conventional and Reduced Sight Distances by Design Speed

Design Speed (mph)	Conventional Design f	Sight* Distance (feet)	Reduced Design f	Sight** Distance (feet)
20	0.35	112	0.40	77
25	0.35	151	0.375	111
30	0.35	196	0.35	152
40	0.32	314	0.33	250

* Sight distance can be calculated using 2.50-second reaction time by the relationship (AASHTO, 1965):

$$SD = \frac{V^2}{30f} + 1.47 \times V \times RT$$

where RT = reaction time, sec.

** Sight distance can be calculated using 1.50-second reaction time and relationship above.

g. It should be noted that the current practice of increasing the curve radius simply to provide additional sight distance generally works only in the higher design speed ranges. At lower speeds, this design concept is invalid because the driver recognizes the reduced degree of curvature and increases his operating speed, thus negating the increased sight distance (McLean, 1979).

h. A final consideration related to horizontal alignment is the tolerance of design speed compared to actual speeds around curves. As design speeds increase, this tolerance actually increases (Glennon,

1979). At design speeds of 20 miles per hour, no tolerance should be planned for, whereas a tolerance of 5 miles per hour may be appropriate for design speeds of 30 miles per hour. This is illustrated in Table 2 as one compares the design speed to the high critical speed.

i. Vertical alignment in the design of recreation roadways is also of critical concern. No general reference providing recommendations for reduced design standards for low volume recreation roadways was identified. General design standards typically follow those shown in Table 4 (Kearney, 1979).

Table 4
Maximum Grades for Low Volume Roadways
by Terrain Condition (Kearney, 1979)

DHV* (vph)	Level	Maximum Grade (%)	
		Rolling	Mountainous
100	7	10	12
100-400	7	9	10
400	6	7	9

* DHV = design hourly volume; vph = vehicles per hour.

j. Design of the vertical alignment is also affected by using the reduced sight distances discussed previously. Conventional design criteria (AASHTO, 1965) could be reduced for the lower design speeds and reduced reaction times. Conventional design factors for vertical alignment are shown in Table 5 (AASHTO, 1971) and reduced values for lower design speeds are presented in Table 6.

k. The final geometric design standard evaluated during this study was the cross section elements criteria. The primary elements of cross section design which are of major importance are the roadway width, shoulder width, and front and back slopes. For recreational roadways, conventional designs require 20-foot road widths for two-way operation and 11- to 12-foot road widths for one-way operations

Table 5
K Factors for Minimum and Desirable Stopping Sight Distance*
(AASHTO, 1971)

Design Speed (mph)	Minimum K Factor**		Desirable K Factor	
	Sag (ft/%)	Crest (ft/%)	Sag (ft/%)	Crest (ft/%)
30	35	28	35	28
40	55	55	60	65
50	75	85	100	145

* Length of vertical curve may be calculated by multiplying the algebraic difference in grade by the appropriate K factor (AASHTO, 1971).
 ** K = measure of the rate of vertical curvature.

Table 6
K Factors for Stopping Sight Distance for Reduced Standards

Design Speed (mph)	Stopping Sight Distance (ft)	Desirable K Factor	
		Sag* (ft/%)	Crest** (ft/%)
20	77	9	5
25	111	16	9
30	152	25	17
40	250	49	45

* K factor is calculated from the relationship (AASHTO, 1965):

$$L = \frac{GS^2}{400 + 3.5 \times S}$$

where:

$$L = KG$$

L = length of vertical curve, ft

G = % grade $\div 100$

S = headlight sight distance

substituting for L yields the relationship:

$$K = \frac{S^2}{400 + 3.5 \times S}$$

** K factor is calculated from the relationship (AASHTO, 1965):

$$L = \frac{GS^2}{1400}$$

where:

$$L = KG$$

S = minimum stopping sight distance

substituting for L yields the relationship:

$$K = S^2/1400$$

(National Park Service, 1968). No distinction is made on the basis of use and area. Such design standards may be relaxed slightly and still provide a safe, comfortable, and economical design. General tendencies should be toward 8- to 10-ft lane widths which would reduce costs and still accommodate the larger vehicles found in recreation areas. In congested areas where traffic and pedestrian volumes are higher, roadway widths should be increased to the recommended design values to promote maximum safety and to reduce driver concern.

1. Shoulder design should be provided in accordance with the intent of shoulders, i.e., to provide a safe, stable area for emergency stops. Most standards call for a 2- to 4-foot shoulder width which should be paved or sodded. Economics generally dictate sodded, compacted shoulders which require only mowing for maintenance. Research (Irick, 1979) has shown that for average daily traffic values less than 750 vehicles per day, sodded shoulders may be provided for approximately \$750 per mile with little or no maintenance required except mowing. The degree of mowing required is dependent upon the selection of suitable grass species. Sodded, compacted shoulders should definitely be considered for recreation area roadways.

m. In summary, conventional geometric design standards may contribute to the general perception of recreation roadway overdesign. Reduced traffic speeds allow a reduction of roadway design criteria with a resultant potential cost savings. The design criteria developed in the CERL study (1975) represent sound engineering standards for the design of recreation roads. Recreation roadway overdesign is primarily the result of failure to account for reduced design speeds and traffic volumes.

5. Pavement Materials and Design Criteria.

a. The third area of roadway implementation investigated for possible cost savings through use of I/A practices is the design of the

pavement structure. Unfortunately, due to variations in geology, topography, and climate, it is quite impossible to develop a uniform set of design standards for construction of pavement structures. However, it is possible to develop generalized concepts for design of low volume roads associated with recreation area developments. Based on a 1980 survey of District and Division personnel, flexible pavement structures are predominant in CE recreation areas. Results of this survey also indicate that, in general, designers recognize the unique nature of recreation roads and are attempting to use the most economical pavement structural design. Pavement structures selected usually include some type of subgrade, a native or select material subbase, a select material base, and a double bituminous surface treatment or asphaltic concrete surface course. Thicknesses of the various courses were determined as a function of either: (1) the funds available for construction, or (2) a rational design based on traffic projections and subgrade strength. Although CE designers appear to understand the reduced design criteria that can be utilized for recreation area pavements, a brief review of conventional and I/A design techniques may be of value.

b. Pavement structure design may be viewed as a two-step process: (1) selection of the pavement type; and (2) structural design of the pavement section based on anticipated traffic load, traffic volume, and underlying soil strength. For the design of pavements for recreational roadways, several conventional and I/A design techniques have been presented in the literature. These various methodologies will be discussed including their anticipated application to recreational roadway pavements. First, conventional and innovative structural design techniques will be discussed. Second, a brief review of recent developments in I/A pavement types will be presented.

c. Conventional low volume pavement designs based on anticipated traffic characteristics and underlying soil strength have been developed by a number of authors. Ahlvin and Hammitt (1975) present a detailed procedure for the design of low volume roadways based on studies

conducted at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. This study was used in the development of Technical Manual (TM) 5-822-5, "Engineering and Design - Flexible Pavements for Roads, Streets, Walks, and Open Storage Areas" (Department of the Army, 1980). The design methodology presented therein is based on the traditional use of the California Bearing Ratio (CBR) value. A 1980 survey revealed that several Districts base recreational roadway structural design on TM 5-822-5.

d. For conventional low volume pavement designs, Greenstein and Livneh (1979) present a simplified methodology based primarily on the previous work of Hammitt and Aspinall (1970). The design method presented is a single layer pavement with a surface of either hot mix asphaltic concrete or a single bituminous surface treatment. The methodology is theoretically based, but results have shown that a reasonable pavement thickness can be determined as a function of traffic loading and applications and the subgrade CBR.

e. McCullough (1979) presented a system which can be used for the design of conventional Forest Service roadway pavements. The pavement design methodology is essentially a modified AASHTO Interim Guide method for low volume roadways.

f. Conventional flexible pavement design incorporates various layers of native or select granular material surfaced with a bituminous surface course. Full-depth asphalt methods, i.e., placing asphalt directly on the subgrade, has been proposed. Evaluation of full-depth asphalt as compared to conventional crushed stone pavements has been conducted at the Cold Regions Research and Engineering Laboratory (CRREL) (Eaton, 1976). Full-depth asphalt is designed to provide the same structural capability as conventional designs with much less pavement thickness. During the CRREL study, test sections were prepared and evaluated. Overall results were as follows:

- (1) Overall frost penetration through the subgrade was the same,
- (2) the thaw condition existed for a very short period of time in the crushed stone sections as compared to the full-depth sections,
- (3) twice as many freeze-thaw cycles were observed under the full-depth sections as opposed to the crushed stone sections because of the thinner pavement sections required, and
- (4) a steady increase of the subgrade moisture content was observed under the full-depth sections.

Even though these results would seem to indicate that the full-depth sections would experience severe distress, the 3-year tests did not reveal any problems. Further evaluation of the test sections is expected to reveal the anticipated distress problems, particularly the increased freeze-thaw cycles and the increased subgrade moisture content.

g. The State of Minnesota evaluated 26 test sections using full-depth asphalt pavements (Lukanen, 1979). The major conclusions of the research are as follows:

- (1) Peak pavement deflections occurred in late May as opposed to conventional pavements occurring in mid-April,
- (2) maximum pavement deflections occurred over a much longer period than for conventional pavements extending through the month of August,
- (3) periods of pavement weakness could not be sharply identified as for conventional pavements,
- (4) for low volume roadway pavements (5.0- to 9.0-inch thicknesses), deflections were very sensitive for pavement thickness, and
- (5) edge stability proved to be somewhat improved over conventional pavement designs.

h. Several researchers have investigated the use of asphalt emulsion mix designs. In general, these mix designs have proven to be

economical and environmentally feasible (Waller, 1980). The general problems involve the lack of a generally acceptable mix design methodology. The type and grade of emulsion for various aggregates have not been adequately quantified. The amount of water to be added and the percentage of emulsion for aggregate coating have not been determined for the various combinations of aggregates. The primary advantage of emulsions is that the use of emulsions offers a wider choice of aggregate gradations. If an aggregate meets the conditions listed below, that aggregate will provide an acceptable emulsion asphalt mix:

- (1) less than 20 percent passes #200 sieve,
- (2) sand equivalent of at least 25, and
- (3) plasticity index times the percent passing #200 sieve is less than or equal to 72.

Waller (1980) reviewed nine emulsion mix design methods and presented advantages and disadvantages of each. The design methods discussed were as follows: (1) Asphalt Institute Method, (2) U. S. Forest Service Methods for Dense and Open-Graded Mixes, (3) Chevron Method, (4) FHWA Region 10 Methods for Dense and Open-Graded Mixes, (5) Armak Method (modified Marshall Method), (6) McConaughay Method for Hot and Cold Mixes, (7) Arizona Method, (8) Illinois Method, and (9) Purdue Method. Emulsion design methods have been extended for low volume roadways (Darter, Wasill, and Shlfiedl, 1980). Primary materials involved dense-graded sand gravels or crushed limestone aggregates. Asphaltic contents generally ranged from 3.5-4.5 percent and were selected to maximize the aggregate soaked stability. Open-graded asphalt emulsions have also provided reasonable low volume pavements (Hicks, Walter, and Williamson, 1980). The Forest Service, Chevron, and FHWA Methods were summarized for open-graded asphalt emulsion mix designs. The basic design steps for each method are as follows: (1) select suitable aggregate, (2) select suitable emulsion type, (3) select the amount of emulsion and water, (4) compact the mix, (5) cure and moisturize the sample, and (6) test the specimen. Hicks and Hatch (1979) tested various

open-graded asphalt emulsions for low volume roadways using hot and cold mix designs. The primary basis of investigation was the U. S. Forest Service layer coefficients with a modified AASHTO Interim Guide Method. Layer coefficients were developed for the various emulsions tested, and failure criteria for field evaluation of the hot and cold mix test sections were established. The general recommendation was that asphalt emulsions could be used successfully as long as at least a 2.5-inch thickness was used. Substandard aggregates were stabilized with cold mix asphalt emulsions for low volume roads in Illinois (Hicks and Hatch, 1979). Asphalt contents were somewhat higher than with conventional aggregates, but the results showed that asphalt contents of 5.5-6.5 percent would yield asphalt emulsion contents of 7.9-9.3 percent by dry weight. Water content needed to be 3.0-5.0 percent by weight. Cold mix designs provided reasonable results and, in the face of rapidly disappearing quality aggregates, substandard aggregates could be used successfully for low volume roadways.

i. An alternate design for low volume pavements uses mastic asphaltic concrete pavements in which the asphalt is heated to 410°-450°F. This design provides the advantages of zero voids, long design life, high durability, very waterproof, skid resistant, and can be constructed in cold weather. Disadvantages are high initial cost, dangerous temperatures for personnel handling the material, and inability to maintain traffic during construction.

j. Another productive area of investigation has been the attempt to develop new base stabilizing and pavement surfacing materials. Various materials have been investigated which may have some application to the construction of recreational area roadways. In general, however, it must be stated that the techniques presented below have not proven to be cost-effective or have general applicability. Investigations into alternative materials have included:

(1) Waste material aggregates,

- (2) substandard natural aggregates,
- (3) sulphur-asphalt pavements,
- (4) rubber-asphalt pavements,
- (5) econocrete and other pavements, and
- (6) base stabilizers.

k. Miller and Collins (1976) investigated the use of solid waste materials from sanitary landfills and the residue materials from power plants. Most waste material examined proved to be unacceptable for any phase of the pavement or subgrade; however, it proved to be fairly acceptable for use in embankments and shoulders. Anderson, Usman, and Moulton (1976) investigated the use of power plant residuals as base and subbase materials. The materials were found to be fairly acceptable as base and subbase materials; however, they were found to be unacceptable for surfaces. Currently, these materials do not meet generally accepted mix specifications, but, if used carefully, can provide reasonably stable base courses. Boiler slag can be used as an extender for aggregates up to 50 percent of the mix. Dry bottom ash was also tested for base courses and was recommended for use in base aggregates and shoulder mixes. No limit was expressed on the percentage of dry bottom ash that could be used as an aggregate replacement.

1. Various methods have been presented to stabilize aggregates which do not meet current specifications for use in pavement mix designs. Cady et al. (1979) investigated aggregate coatings as stabilizing agents. Epoxy coatings tended to lower Marshall stability, tensile strength of the pavement, and stiffness of the mixture. Raw kraft lignin also proved unacceptable as a pavement admixture. The overall effects of the lignin were not as significant in concrete as they were in bituminous mixtures. The lignin tended to react with the binder courses in each case, however, and proved to be unacceptable for use in either case. Later studies of marginal aggregates for use in low volume

roadways provided a little better results (Grau, 1980). For roadways with design lives of 10-15 years, sandy clays and sandy clay gravels were tested. The general requirements for a successful mix design were as follows:

- (1) 100 percent should pass 1.5-inch sieve and 15 percent should pass #200,
- (2) asphalt content should be 5.5-6.5 percent,
- (3) stability should be at least 300 pounds, and
- (4) retained stability should be at least 50 percent.

The results of most studies appear to be promising; however, the common problem of all designs tested was edge raveling and associated maintenance problems.

m. Sand-asphalt combinations have been investigated extensively (Barksdale, 1980; Potts, Ruth, and Smith, 1980). Original designs (Barksdale, 1980) proved to be generally poor, resulting in excessive rutting and premature fatigue distress at test sites in four south-eastern states. Design mixes proved to be fairly satisfactory for sub-bases and leveling courses as long as the asphalt content was high (6.5-7.5 percent) and at least a 3-inch surface was used. Asphalt contents could be reduced to 4-5 percent if 6-inch surface courses were used. The general characteristics of the sand were that the sand equivalent must be over 24 and clay content should be from 4-7 percent. Potts, Ruth, and Smith (1980) investigated the addition of lime rock to a sand-asphalt pavement in Florida. Generally, the addition of lime rock aggregate provided fairly stable surfaces and good base courses. Mix design must be performed very carefully as the lime rock proved to be highly susceptible to water. Base course rutting was a problem, and surface course rutting was severe. The Forest Service (Stuart, Skok, and Stehly, 1975) has investigated the use of sand-asphalt base materials in Minnesota. The use of the asphalt-stabilized sand base appeared to be economically attractive. The estimated cost (1975) of the

sand-asphalt construction was \$23,360 per mile whereas conventional construction was estimated to cost \$35,200 per mile. It should be pointed out, however, that economics of the asphalt-sand concept are highly dependent on the cost of asphalt cutbacks.

n. Sulphur has been added to asphalt to reduce the overall use of asphalt and still provide a stable roadway pavement. Earlier tests were run with sulphur-asphalt ratios of 0-100, 20-80, and 50-50 (Kennedy et al., 1977). The general results proved favorable with the sulphur-extended asphalt designs improving the fatigue life of the thicker sections (72 inches). On thinner sections, increased sulphur content caused much stiffer sections and the pavement required a very stable subgrade. The modulus of elasticity improved as sulphur content increased to 50 percent, but showed no improvement beyond that point. The major parameters of concern involve the interactive effects of the sulphur content, penetration of the asphalt, and temperature. Later research (Kennedy and Haas, 1980) proved that the economics of sulphur-extended asphalt pavement would prove even better as asphalt costs increase. As long as the relative cost is about 2.2 to 1, the pavement mix designs will be considered economical.

o. The use of rubberized asphalt has been proposed as a technique for recycling old tire casings and providing an improved roadway surfacing technique. Schnermeier (1975) reported on the use of rubberized asphaltic seal coats applied to low volume streets in Phoenix, Arizona. Alternative designs consisted of soil cement stabilized base, asphalt concrete, and asphalt rubber seal coat. The design proved to be very durable and provides a relatively maintenance free surface. Costs of asphalt rubber seal coat were found to be 2-1/2 times more than standard asphalt seal coats; however, they were determined to have a service life 2 to 3 times greater than the standard seal coat. Placement of the rubberized asphalt directly on a soil cement subgrade or other base course has only been partially successful.

p. Econocrete is a lean concrete that can be made with generally low cost, locally available aggregates that do not meet conventional specifications (Yrjanson and Packard, 1980). Investigations involved the use of econocrete as subbase courses under concrete pavements, composite concrete pavements, base courses under bituminous pavements, and shoulders adjacent to concrete pavements. General test results proved favorable and research is now continuing to determine the medium- to long-range design characteristics of econocrete.

q. Roberts and Kennedy (1980) investigated the feasibility of a no-maintenance flexible pavement. Tests revealed that the pavement structure was too thick to require no maintenance over the assigned life of the pavement. Mix design would have to compromise various distresses in the pavement in order to provide an economical pavement section. The design procedure presented produced pavements which were structurally sound but prohibitively expensive. Extreme care would be necessary to utilize this design methodology and to provide an economical pavement.

r. In summary, the WES study of the use of a variety of I/A stabilizing and pavement materials for construction of military roadways determined that the most cost-effective pavement sections are compacted base materials with a single or multiple bituminous surface treatment or asphaltic concrete surface course. The most cost-effective subgrade and base course stabilization techniques are soil cement or lime treatment, and TM 5-822-5 provides excellent guidance on the design of pavement structures for low volume roads found in CE recreation areas.

6. Roadway Maintenance and Restoration.

a. The final area addressed under this study was that of roadway maintenance and restoration. Low cost maintenance techniques for low volume roadways have long been a topic of major concern, and many maintenance techniques have been developed and tested over the past

10 years. In this section, the following maintenance design and/or techniques will be evaluated:

- (1) Pavement overlays,
- (2) recycling of pavements,
- (3) innovative maintenance techniques, and
- (4) economics of pavement maintenance.

b. Pavement overlays have long provided a reasonable method of restoring a pavement's structural value. Montsmith (1979) outlines the general methods of overlay design and pavement evaluation as well as maintenance and rehabilitation techniques. Other researchers (Darter et al., 1979) have developed specific design methods applicable to overlays on low volume roadways. The Darter et al. (1979) method is outlined as follows:

- (1) Determine the estimated number of 18-kip equivalent axle loadings (EAL),
- (2) estimate the present serviceability index and salvage value of the existing pavement structure,
- (3) estimate the existing pavement component thickness from historical records,
- (4) determine equivalent pavement thickness,
- (5) develop a design thickness curve by using the present-worth thickness of the dense-graded aggregate as the basic structure,
- (6) determine the total thickness of the various asphaltic concrete courses,
- (7) determine the CBR of the subgrade,
- (8) determine the design thickness,
- (9) determine total pavement thickness, and
- (10) determine total overlay thickness.

c. Methods of evaluating the structural value of existing pavement structures comprise an integral part of the overlay design procedure. Evaluation of the overlay design by pavement deflection analysis (Sherman and Hannon, 1971) is one of the more widely accepted methods of pavement evaluation. Reasonably good correlations have been found between the California dynamic deflection and the modulus of subgrade reaction for existing bituminous roadways. The modulus of subgrade reaction may then be used in the structural design of the overlay using such design methods as the AASHTO Interim Guide (AASHTO, 1972). A second method of deflection design utilizes the Benkelman beam to measure deflection of the existing pavement (Voss, 1971). Two test sections in Washington were evaluated and a design methodology was developed using the elastic layer concept and fatigue as a design life determinant. Results of the design method provided overlay thicknesses that were slightly conservative when compared to other design methods. Two methods of design were used to design overlays for five different pavement combinations (Copas and Pennock, 1972). A monolithic evaluation design was used to determine the thickness of an asphaltic overlay over an asphaltic pavement. Layer analysis techniques were used to evaluate the four other pavement combinations:

- (1) Asphaltic concrete overlay over asphaltic concrete pavement,
- (2) asphaltic concrete overlay over portland cement concrete pavement,
- (3) portland cement concrete overlay over asphaltic concrete pavement, and
- (4) portland cement concrete overlay over portland cement concrete pavement.

d. A simplified method of designing structural overlays was developed in California by analyzing test sections along 450 different roadways (Bushey, Baumeister, and Matthews, 1976). The method was based

on deflection measurement of the existing pavement and provided very predictable results on 69 specific test sections. The method did not, however, provide for the prevention of reflective cracking. General rules of thumb were presented, but they limited the value of the overall design scheme. No specific recommendations were made which allowed for the extrapolation of the design for low volume roadways. In a study by Way (1980), the problem of reflection cracking in overlays of a 9.0-mile section of Interstate 40 in Arizona was addressed. For overlays of less than 4.0 inches, five treatments were investigated:

- (1) Asphalt-rubber membrane seal coat placed under the asphalt concrete finishing course,
- (2) asbestos plus 3 percent asphalt,
- (3) heater scarification with reclamite (surface recycling),
- (4) asphalt-rubber membrane flushed into the asphaltic concrete overlay, and
- (5) 200/300 penetration asphalt.

The asphalt-rubber membrane seal coat caused a great deal of pavement shifting and resulted in a very rough riding surface. Eventually, the pavement became very unstable. The asphalt-rubber membrane placed between the overlay and the existing pavement provided reasonable resistance to reflective cracking. Heater scarification did not reduce the amount of cracking, but did reduce the length of the individual cracks.

e. An overlay design method for overlays on rigid pavements (Seeds et al., 1980) was tested on three test sections near San Antonio, Texas. The primary advantage of the method is that it provides rational solutions instead of conventional methods that force designers to model complex pavement combinations, i.e., an asphaltic concrete layer sandwiched between two reinforced concrete layers. Deflection data required for the design methodology can be obtained with minimal traffic interference. Evaluation of the pavement overlays will require 5 to 10 years, but

initial results show that the design method is very flexible and does produce practical designs.

f. Recycling of pavements is a relatively new procedure of reconditioning an existing pavement and providing an economical smooth riding surface. This procedure was examined for techniques concerning surface courses, base courses, and various pavement materials (Epps, 1978). For surface recycling, approximately the top 1.0 inch should be reworked. Epps (1978) outlined five methods and gave the description of the equipment required for each method. In addition, typical costs per square yard for a 1-1/2-inch recycle project were listed with the fuel requirements and production capability of the required machinery. Two in-place surface and base recycling techniques were presented. The techniques selected should be based on the thickness of the pavement to be treated and the thickness of the surface course. The major advantage of in-place recycling is the ability to improve the structural capacity of the pavement without significantly altering the horizontal or vertical alignment of the roadway. The major disadvantages are that quality control is not easily evaluated. Pulverization is difficult on concrete, and interruption of traffic is absolute. Four alternative construction company techniques were presented and typical costs per square yard given for various pavement types. The State of Arizona (McGee and Judd, 1978) just attempted asphaltic recycling on a 5.3-mile section of state highway. Approximately 22,000 cubic yards of asphaltic concrete was salvaged and blended with mineral aggregate, paving asphalt, and extender oil. Production rates of 325 tons/hour were achieved at 200°-205°F with approximately 2 percent moisture added. A blend of AR 2000 at 2.7 percent with 50 percent extender oil was added to 80 percent crushed asphaltic concrete and 20 percent new mineral aggregate. A total saving of approximately \$4.00 per ton was achieved. A general overview of recycling methods and procedures is presented in Epps, Little, and Holmgreen (1980). Basic guidelines for recycling portland cement concrete pavements and asphaltic concrete pavements are

presented plus detailed information on preconstruction conditions, construction procedures, and postconstruction evaluation.

g. Innovative techniques involving maintenance and construction materials have become critical due to the highway construction industry's demand on growingly scarce materials and a labor-intensive product. In response to this need, the Texas Highway Department (Epps and Gallaway, 1974) has developed techniques for maintenance of materials, pavements, shoulders, and structures. Lightweight aggregates have been used extensively in seal coats and in hot-mixed asphaltic concrete. These materials have produced prolonged and initially high skid resistance and stable pavement characteristics. Methodologies have been developed for the manufacture and placement of hot-mixed cell-laid synthetic aggregate asphaltic mixtures for winter and summer patching. Edge repair techniques have been developed which produce savings over conventional methods of 4.5 to 6.5 cents per linear foot. Pothole repair is accomplished with conventional hot-mixed asphalt concrete placed hot in the hole which has been "preheated" with a "hot box." Burners are used to keep the material in place at the desired temperature. Cost, including labor, is approximately \$50 per ton. Ground rubber tires (Morris and McDonald, 1976) have been combined with hot asphalt with a ratio of 25 percent rubber to 75 percent hot asphalt. The process has been used in full-scale field projects in the form of stress-absorbing seal coats and interlayers and as waterproof membranes. A total of 2000 lane-miles of roadway tested produced a high capacity to absorb direct tensile, flexural, and shearing stresses. Other uses for the membrane are to prevent reflective cracking of overlays, provide bridge deck protection, control differential movement of existing pavements constructed over expansive clays, provide economical construction of low volume roadways, and provide improved elastomeric sealing of cracks and joints.

h. Herrin (1979) evaluated the use of innovative patching methods using bituminous pavement materials (typical costs are presented in

Table 7). Patching mixtures are generally classified as either: hot-mixed, hot-laid; hot-mixed, cold-laid; or cold-mixed, cold-laid. Any patching material should have the primary characteristics of: stability to allow the patch to resist displacement by traffic, stickiness to stick to the existing pavement around the edges of the hole, resistance to water action to prevent binder stripping from the aggregate, durability to prevent raveling or cracking, skid resistance to provide traction, workability to enable the material to be placed easily, and storability to allow the material to be stockpiled.

Table 7
Cost of Patching Materials in East
 Central Illinois

Type of Patching Mixture	Cost (\$/Ton)
Hot-mixed, hot-laid (asphalt concrete)	19.50
Hot-mixed, stockpiled (using MC-250)	18.50
Hot-mixed, stockpiled (using MC-250 and anti-stripping agent)	19.05
Cold-plant mixed, stockpiled (using HFE-300)	14.75
Pay-Rite proprietary mix (using MC-250 and proprietary additive)	22.50

i. Faiz and Edgardo (1979) evaluated road user and construction costs of low volume roadways. The method they developed employed findings related to the deterioration of the pavement caused by the traffic and its effect on vehicle operating costs. The methodology was designed to eliminate the subjective estimation of vehicle operating costs as they are affected by the quality and quantity of maintenance operations. Gravel surfaces become economical at the 45- to 60-vehicles-per-day volume as compared to earthen roadways.

j. In summary, a variety of innovative maintenance and restoration techniques have been evaluated. As standard materials run short, there will be an increasing emphasis on the development of more

economical maintenance and restoration techniques. Unfortunately, the variability of climates and geology makes generalization concerning the cost-effectiveness of such techniques quite indefensible. Maintenance techniques must be evaluated on a site- and project-specific basis. A determining factor in the decision to use innovative techniques is the geographic availability of the proposed restoration materials since many of the materials proposed are not widely available at the present time.

7. Summary.

a. The implementation of a roadway system for recreation areas generally requires efficient conduct of five activities: (1) accurate traffic volume and type projection, (2) environmentally sound route planning, (3) geometric design based on suitable criteria, (4) pavement structural design recognizing traffic volume and loads applicable to recreation area development, and (5) cost-effective pavement maintenance.

b. Cost savings in the construction of recreational area roadways can be realized through the use of geometric and pavement design criteria which recognize the unique nature of the traffic found at recreation sites. These criteria are currently available in the form of reports, EM's, and TM's. The CERL report (McNamara, Moore, and Baerwald, 1975) and TM 5-822-5 (Department of the Army, 1980) provide excellent guidance in the geometric and structural design of low volume roads. Although several Districts reported using these guides, others appear to be unaware of their existence.

c. Cost savings can be realized through implementation of standardization planning and design techniques. Computerization of the route planning and geometric design process appears to offer significant cost savings.

d. Although innovative pavement materials are being evaluated that generate a lot of publicity, it would appear that the CE practice of using single or multiple bituminous surface treatments or asphaltic concrete surface courses is the most cost-effective at the present. However, attention should be given to pavement structural design techniques. Where stabilization of subgrade or base materials is required, lime or cement appear to be the most cost-effective materials. Therefore, it is recommended that further research and development into innovative pavement materials not be attempted at this time.

e. Appropriate criteria for design of cost-effective and environmentally sound recreation area roadways are currently available. These criteria must be recognized and applied by the recreation area planner and the roadway designer. The overall planning and design effort must be a coordinated effort between the planner and the engineer. This process is cooperative in nature requiring input from the engineer during the planning process and feedback from the planner during the design phase. The major constraint to the implementation of a cost-efficient roadway system appears to be accurate forecasting of recreation area visitation and translation of visitation estimates into traffic volumes and loads. A cooperative effort between the planner and the engineer is necessary to overcome the inherent problems in visitation forecasting. This effort and implementation of appropriate planning, design, and construction can result in the provision of safe, environmentally sound, aesthetically pleasing, and economical roadway systems at CE recreation areas.

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